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Two B's, or Not Two B's? An NPOI Survey of Massive Stars

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Abstract. Surveys of massive O- and B-type stars suggest a significantly higher multiplicity fraction than for Solar-type primaries, but coverage over the complete separation range is incomplete. Understanding the distribution of the separation of these companions is important when considering the formation and survivability of disks and proto-planetary systems around these massive stars. We detail the status of an ongoing volume-limited ($D < 75$ parsecs) multiplicity survey of B-type stars covering this important separation range between 1 and 15AU, complemented by AO observations to resolve wider companions. The angular resolution provided by the Navy Prototype Optical Interferometer (NPOI) allows for the detection of close (5–700mas) binaries with a magnitude difference reaching ΔR of ~3. With our large, unbiased volume-limited sample of 69 targets, these observations will allow for the first constraint on the multiplicity of these massive stars over this separation range. This survey will be complementary to both previous spectroscopic surveys and speckle interferometry observations. Newly resolved companions within this study will make ideal targets for follow-up interferometric observations to detect orbital motion and determine their orbital parameters. Future interferometers will extend this work to closer, fainter companions around both these targets and intrinsically fainter A-type stars.

1. Introduction

High-resolution observations of stars and other astrophysical phenomena with ground-based interferometry can be used to probe processes and structures on small angular scales, unresolvable by large single-aperture optical telescopes. Modern optical and near-infrared interferometers have baselines up to 150 meters, corresponding to a resolution limit of 1 mas at 800 nm. This significant improvement in resolution over traditional imaging has allowed for the detection of close binary systems (e.g., Patience

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et al. 2008; Zavala et al. 2010), and the characterization of circumstellar material (e.g., Eisner et al. 2009; Hughes et al. 2009). Combining interferometric measurements with adaptive optics (AO) observations will result in significant coverage of the total companion separation distribution.

2. Sample

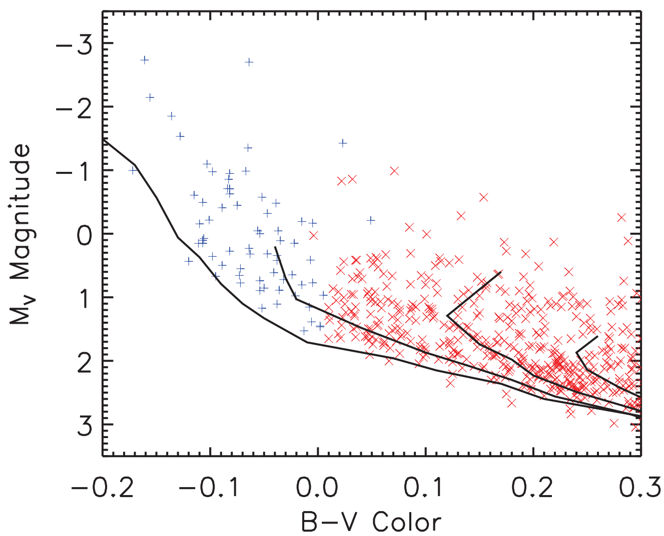

Figure 1. The 69 targets within our volume-limited sample (blue pluses) plotted on a color magnitude diagram. Overplotted are the 10, 250, 500, 800Myr isochrones from Siess et al. 2000. For context, the 500 targets of our ongoing volume-limited A-stars survey are also plotted (red crosses). These two complete datasets will provide the first constraints on the multiplicity for this mass range.

A volume-limited sample of 69 B-type stars was selected from the *Hipparcos* Catalogue (ESA 1997) based on two primary criteria—a distance of less than 75 parsecs, and a $B-V$ color less than 0.0, consistent with B-type stars. A minimum parallax of $\pi = 13.3$ mas measured by the *Hipparcos* satellite—corresponding to 75 parsecs—was applied to the complete catalog. In order to ensure accurate determination of the physical parameters of the targets, those with large parallax uncertainties ($\sigma_\pi \geq 5.5\%$) were removed. The second criterion was applied based on the $B-V$ colors expected for B-type stars (Kaler 1989). The lack of O-type stars within 75 parsecs removed the requirement for an additional color cut-off at a $B-V$ color of -0.29. Finally, white dwarfs were removed from the sample by removing targets with a low absolute magnitude. Presently, the sample is limited by the observable declination limit at the Anderson Mesa and Mauna Kea Observatories ($\delta \sim -25°$); future measurements at Southern observatories will complete the sample.

Table 1. Sample and Observations

HIP	Scans	AO	HIP	Scans	AO	HIP	Scans	AO	HIP	Scans	AO
301	0		25336	1566		67301	1196	✓	95619	–	
677	102		25428	388		74376	–		96465	–	✓
2484	–		26966	0		74785	244	✓	98495	–	
7588	–		28380	347		77516	626	✓	100751	–	
8832	0		34899	–		77634	–		101867	184	
10602	–		36188	940		79101	532		101958	42	
11484	21		36917	–		82673	319	✓	107380	–	
12394	–		41307	54		83207	148		108085	–	
13209	733		42334	–		85727	–		109139	13	
14576	1365		45336	271		85792	–		109268	–	
16083	284		47391	–		90185	–		110395	284	
17797	–		49669	886	✓	92041	–		111497	924	
20042	–		55434	379		92855	–		112029	850	
21281	–		59803	50		93542	–		112948	–	
23362	0		60965	64		93805	841	✓	116231	–	
23767	956		62956	712		95347	–		116805	161	
24244	0		63125	0	✓	95560	0	✓	116971	116	
24305	2										

Targets with '–' within the scans column are below the declination limit at NPOI.
Targets with '✓' within the AO column are those with dedicated AO observations obtained at the CFHT.

3. Observations

The targets within the sample were observed with the Navy Prototype Optical Interferometer (NPOI – Armstrong et al. 1998) between January 1998 and July 2011, both as science targets in their own right and as calibrator targets for other observations. A total of 15,600 scans were recorded for the targets within the sample, detailed in Table 1. Further information regarding the NPOI observational setup and data recording can be found in Benson et al. (2003) and Hummel et al. (2003). An initial epoch of AO observations has been obtained for this project at the Canada-France-Hawaii Telescope (CFHT), with the KIR instrument (Doyon et al. 1998). These data will be combined with existing archival measurements and with future AO observations to complete this portion of the survey.

4. Discussion

4.1. Multiplicity

Observations of complete populations of nearby stars reveal a trend of increasing multiplicity through earlier spectral type, with M-dwarfs having a multiplicity fraction of 42% (Fischer & Marcy 1992) compared with 57% for solar-type stars (Duquennoy & Mayor 1991). The different techniques employed in detecting or resolving binary companions, such as adaptive optics (AO) imaging, speckle imaging, interferometry and spectroscopy, all probe different portions of the companion separation distribution. This is demonstrated when comparing the multiplicity fractions calculated for B-type stars using AO (23%, Roberts et al. 2007) to that calculated using spectroscopy (74%, Abt et al. 1990). Determining the binary fraction for an unbiased sample of B-type stars over a significant portion of the separation distribution using a number of observational techniques will therefore provide an accurate estimation of the true binary fraction. This study will be combined with ongoing AO observations of the same sample in order to provide the most complete coverage of the separation distribution, the results of which will provide both an important comparison point to studies of lower-mass primaries and our understanding of binary formation processes.

Indirect evidence of the presence of a companion can also be used to estimate the multiplicity of a subset of B-type stars. We have previously shown in De Rosa et al. (2011) that the detection of x-rays from late B-type stars can be indicative of an unresolved companion. Using this method, an initial lower-limit on the multiplicity of B-type stars can be estimated as $\sim 40\%$ (Stelzer et al. 2006). The true multiplicity fraction cannot be estimated by this method as it is not sensitive to companions of spectral type earlier than A7, potentially removing a significant portion of the companion mass ratio distribution from the reported multiplicity fraction. Our interferometric and AO observations will be able to resolve these x-ray quiet companions as well as to verify the presence of the x-ray active companions predicted by Stelzer et al. (2006).

4.2. Dynamical Masses and Orbits

Newly resolved companions with the NPOI observations will provide excellent candidates for orbital monitoring projects due to their close separation and short orbital periods. Similarly, close separation binaries resolved with the AO observations will allow for further refinement to existing orbits (Fig. 2). We have prepared an IDL orbit-

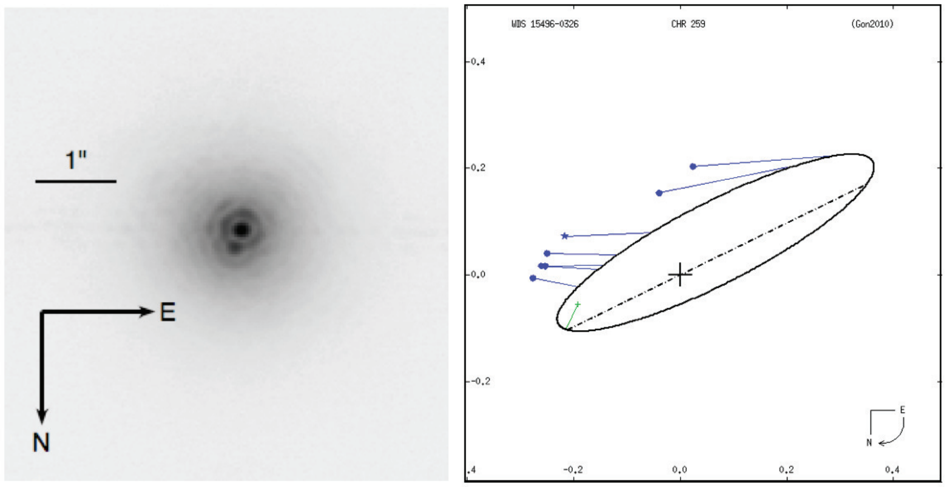

Figure 2. *Left:* The AO observation of HIP77516 resolves both components of this system. The angular separation between the pair ($\sim 0\farcs2$) is approaching the resolution limit of the CFHT. *Right:* The astrometric orbit of this pair taken from the Sixth Orbit Catalog (Hartkopf et al. 2001; Gontcharov & Kiyaeva 2010); the apparent discrepancy is not due to a poor fit in this instance, but instead is a scaling error between the photocentric and true semi-major axes. Our AO and interferometric observations will be complementary to existing orbital motion measurements obtained using other observational techniques, leading to a refinement of the orbital parameters.

fitting code based on a method presented by Hilditch (2001), and similarly used by Köhler et al. (2008), to determine the orbit of the T Tau S binary system. Once an orbit has been determined, with observations covering a significant portion of the complete orbit, a total system mass can be estimated from Kepler's Third Law, with the mass ratio determination requiring further spectroscopic observations. The total dynamical mass of the system can be used to test theoretical isochrones based upon the predicted total mass for a pair of stars at known magnitudes (De Rosa et al., in preparation). Such tests are especially useful for B-type stars as they evolve rapidly on the color-magnitude diagram away from the Zero-Age Main Sequence. Although they are below the current detection limits of the interferometric observations, the detection and orbital characterization of any young M-dwarf companions at close separations within the AO dataset will further test the theoretical models at an interesting phase of the evolution of low-mass stars.

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